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IoT applications utilizing excess heat in electrical lighting fixtures

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Anotace:
Vývoj IoT zařízení bude vždy silně ovlivněn možnostmi napájení systému. Značný počet uzlů IoT (node) vytváří nebezpečí dodatečných nákladů při výměně baterii. Z tohoto důvodu se vývoj napájení uzlů zaměřuje na zařízení, která mohou pracovat bez baterie a energii získávají z jiných zdrojů. Tento článek se zaměřuje na alternativní získání elektrické energie z odpadního tepla vznikajícího při provozu LED svítidel obsahující velkoplošné LED čipy. Pro konverzi odpadní tepelné energie na elektrickou energii je využit Peltiérův článek zapojený ve funkci termogenerátoru do teplotního řetězce.

Annotation:
The development of IoT instrumentation will always be strongly influenced by the properties of the power supply system. A large number of IoT nodes creates a danger of extra expenditures when changing the battery. For this reason, the development of supply nodes tends to prefer systems capable of battery-less operation, obtaining energy from other sources. This article deals with an alternative method of electrical energy acquisition form the excessive heat appearing in LED lighting fixtures utilizing large-area LED chips. A Peltier cell was used for the conversion of heat energy to electrical energy, connected as thermo-electric generator into the thermal chain.

INTRODUCTION

The basic idea of placing the thermo-electric generator [2] directly below the heat source (the COB LED chip) was realized in a modified version consisting of two duralumin wafers inserted between the individual parts of the heat path, providing uniform heat distribution, minimum increase of thermal resistance in the heat path, and permitting placement of temperature sensors. Fig. 1a shows a principal schematic of individual layers´ distribution, Fig. 1b shows the original arrangement of the lamp by its manufacturer.

CONFIGURATION

The measured configuration consisted of an adapted industrial lighting fixture containing two large -area COB LED chips made by the Samsung company [3]. The standard power input of the lighting fixture was 60 W This lamp type was selected for a comparative type of measurement with one chip fitted with a thermo-electric generator while the other used for comparison was left in its original state as applied by the lamp manufacturer. A Peltier cell with low thermal resistance is used as the thermo-electric generator [1]. Equitherm aluminum washers are placed on both sides of the thermogenerator, serving for the application of temperature sensors, intended to assure uniform temperature distribution. A thermally conducting paste was applied to all contact areas in order to minimize the increase of thermal resistance in the temperature chain. The temperature sensors are fixed by thermally conductive cement in a cavity in the center of the aluminum washer. This arrangement provides best accuracy of measurement of the COB LED chip temperature. The whole configuration containing the thermo-electrica generator was fixed by bolts to the lighting fixture body, serving as a passive heat radiator for LED chip cooling by surrounding environment.

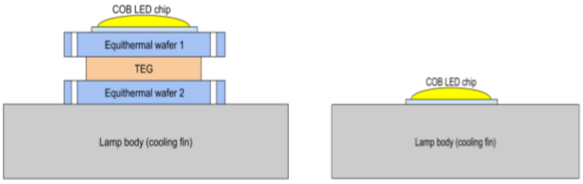


Fig. 1: a) Modified version, b) Original version

TEMPERATURE SENSORS CONFIGURATION

Miniature platinum PT1000 sensors in SMD0805 casing were used as temperature sensors. Two reference points T101 and T104 were added for temperature measurement, permitting to measure the chips temperature under identical conditions and will be used for comparison of the temperature rise of the LED chip configuration with and without a thermo-electric generator. The sensor location is shown in Figure 2 and Figure 3. Description of the temperature sensor locations:

T101 – reference point of the LED chip with a thermo-electric generator, location at the LED chip edge.
T102 – temperature at the hot side of the thermo-electric generator, inside the aluminum washer.
T103 – temperature at the cold side of the thermo-electric generator, inside the aluminum washer.
T104 – reference point of the LED chip without thermo-electric generator, location at the LED chip edge.
T105 – temperature of the lamp body (radiator).

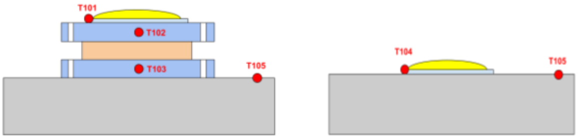


Fig. 2: Location of the temperature sensors

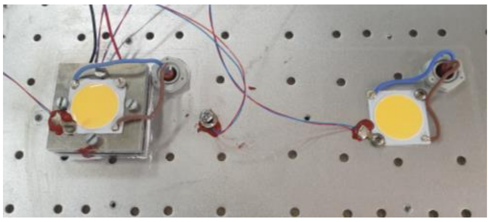
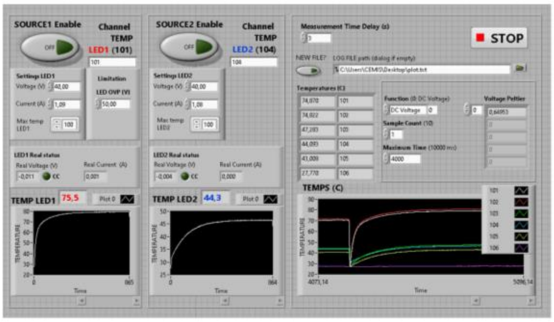


Fig. 3: The measured system, details of temperature sensor placement

MEASUREMENT PROCEDURE

The lighting fixture was operated in three modes – at 20%, 50%, 100% of nominal power input of the light source used in the lamp, and 115%, corresponding to the LED maker recommended operating value of 1080 mA current [3]. The LED chips power input, temperature of the checkpoints and the thermo-electric generator output voltage were followed during the measurement. The measurement took place in a laboratory at room temperature with minimum surrounding air movement. The temperature difference between the T102 and T103 sensors is the determining factor for the thermo-electric generator output power. In Figure 13 you can see the relation between the temperature difference and thermo-electric generator output power. The measurement procedure was automatic, with readings recorded every five seconds. The Labview environment was used to control the measurement process. An aplet was created for measurement instruments control – see Fig 4.



Channel TEMP LED1 (101): 101
Channel TEMP LED2 (104): 104
Measurement Time Delay (s): 1
LOG FILE path (dialog if empty): C:\Users\CEMIS\Desktop\plot.txt
Settings LED1: Voltage (V) 40,00; Current (A) 1,09; Max temp LED1 100
Limitation: LED OVP (V) 50,00
Settings LED2: Voltage (V) 40,00; Current (A) 1,08; Max temp LED2 100
LED1 Real status: Real Voltage (V) -0,011 CC; Real Current (A) 0,001
LED2 Real status: Real Voltage (V) -0,004 CC; Real Current (A) 0,000
Temperatures (C): 74,070 101; 74,822 102; 47,283 103; 44,093 104; 43,008 105; 27,770 106
Function (0: DC Voltage): DC Voltage 0
Sample Count (10): 1
Maximum Time (10000 ms): 4000
Voltage Peltier: 0,64953; 0; 0; 0; 0
TEMP LED1 75,5
TEMP LED2 44,3

Fig. 4: The Labview environment for automatic measurement control

At 20% power the steady state conditions were reached after about 40 minutes´ operation, the temperature difference across the thermo-electric generator reached about 4,3 ^{0}C – see Fig. 5. The influence of the thermo-electric generator and measurement washers can be seen from the T105 (reference diode) and T101 temperature difference (28,5 ^{0}C vs 33,5^{0}C). The chip temperature rose by 5 ^{0}C due to decreased heat drain. This effect becomes important at higher inputs where higher values can be expected. The measurement took place at an environment temperature 25,6 ^{0}C. Form the point of view of energy efficiency of the thermo-electric generator, the steady state was reached sooner, after about 10 minutes of operation. The temperature difference across the thermo-electric generator was 3,4 ^{0}C and with optimum load its measures power output was about *2,8 mW*, see Fig. 6.

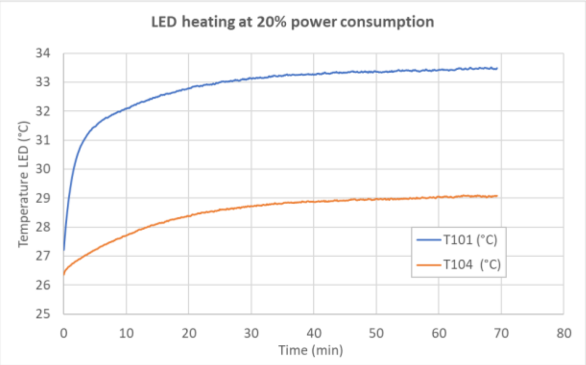


Fig. 5: LED heating at 20% power consuption

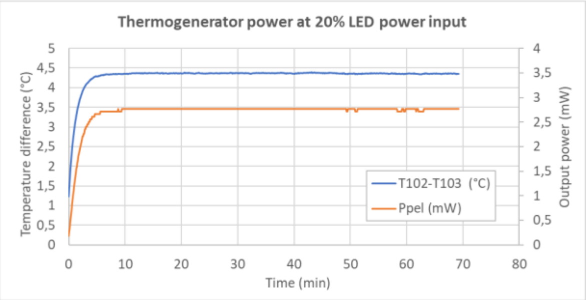


Fig. 6: Thermo-electric generator power at 20% LED power input

At 50% power (see Fig. 7), the temperature steady state was reached after about 40 minute of operation. This time interval is mostly influenced by the thermal capacitance of the lamp cooling fin. The LED chip temperature reached 47 ^{0}C. The temperature difference between the cold and hot side of the thermo-electric generator was about 12 ^{0}C. The measurement took place at the environment temperature 26,1 ^{0}C. At this 12 ^{0}C temperature difference across the thermo-electric generator, the output power reached *21 mW* – see Fig. 8.

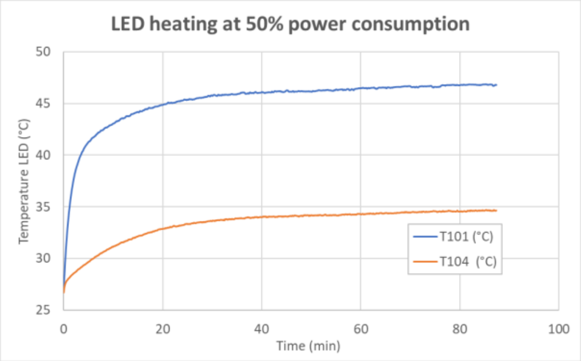


Fig. 7: LED heating at 50% power consuption

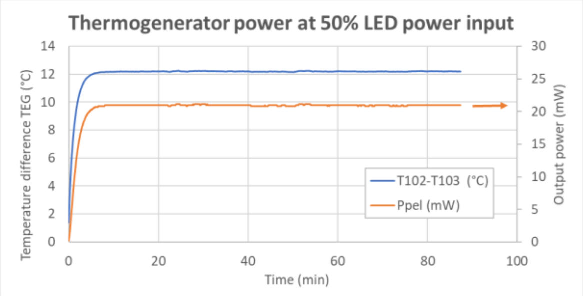


Fig. 8: Thermo-electrc generator power at 50% LED power input

At 100 % power (Fig. 9) can be assumed to be the standard operating mode of the lamp. A distortion of the measured values can be expected to be negligible, due to the low thermal resistance of the wafers. Compared to the standard arrangement (T104) 43,3 ^{0}C temperature, the LED chip surface temperature (T101) rose to 70,6 ^{0}C. The measurement took place at the environment temperature 27,3 ^{0}C. At the temperature difference 27,7 ^{0}C across the thermo-electric generator, its output power reached *104 mW* – see Fig. 10.

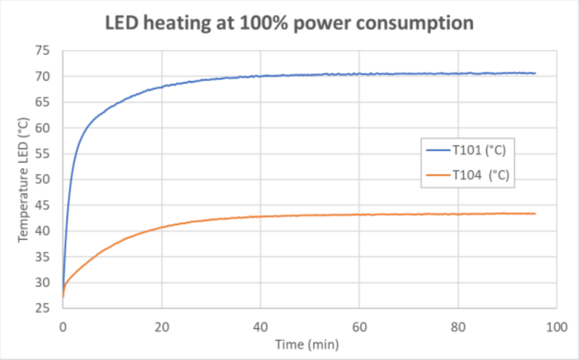


Fig. 9: LED heating at 100% power consuption

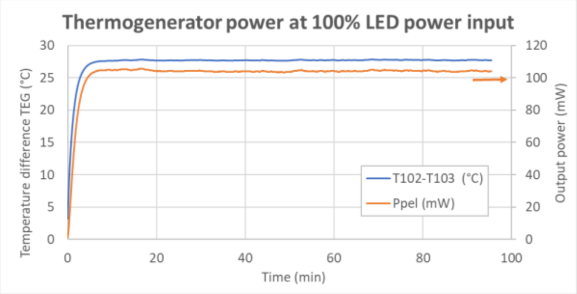


Fig. 10: Thermo-electric generator power at 100% LED power input

At 115% power (see Fig. 11) agrees to the LED chip manufacturer recommendation and only serves to illustrate the maximum obtainable power gain. The LED chip temperature (T101) rose to 79,4 ^{0}C as compared to the standard arrangement temperature (T104) 46,5 ^{0}C. The measurement took place at 27,6 ^{0}C. At the 33,6 ^{0}C difference between the cold and hot side of the thermo-electric generator, the obtainable output power was *150 mW* – see Fig. 12.

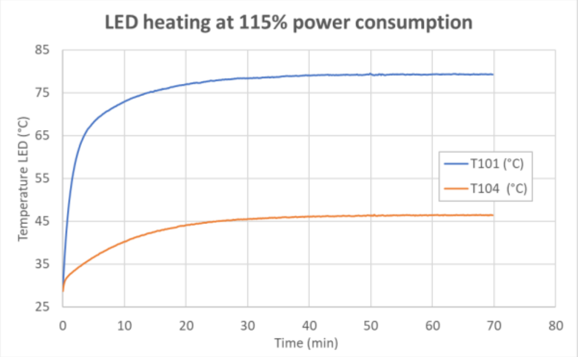


Fig. 11: LED heating at 115% power consuption

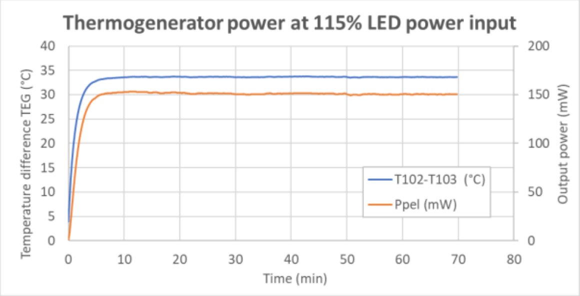


Fig. 12: Thermo-electric generator power at 115% LED power input

SUMMARY

The measurement results on the sample shown indicates that at 100% lamp input power the application of a thermo-electric generator between the LED chip and the cooling fin causes a degradation of thermal transfer (increase or thermal resistance) [4]. However, in spite of this limitation causing a 27,2 °C temperature rise to the final 70,6 °C, the temperature still was below the maximum permitted LED chip temperature specified by the LED chip manufacturer. The thermo-electric generator was producing 104 mW power at 100% lamp power, see Fig. 13. When operating the LED chip at its manufacturer’s recommended operating current value (about 115% of standard lamp current), the temperature rise reached 79,4 °C from the original 46,4 °C. In this operating mode the thermo-electric generator output power rose to 150 mW. The measured system proved that the excess heat of lighting fixtures can be used as a source of electrical energy for IoT instruments power supply [5].

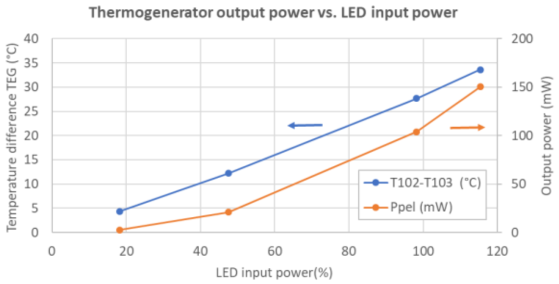


Fig. 13: The measured system, details of temperature sensor placement

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